# Haptic and Audio Displays for Augmented Reality Tourism Applications


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## Abstract

Augmented Reality (AR) technology has potential for supporting applications such as tourism. However, non-visual interaction modalities are undervalued and underused in AR tourism applications. Visual displays are ineffective or inappropriate in some situations such as in strong sunlight or when walking or driving. Meanwhile, non-visual modalities are becoming increasingly important in mobile user experiences. In this paper, two non-visual interaction modalities, haptic display and audio display, and their combination are evaluated in representing tourism information to users with a mobile phone. An experimental evaluation was conducted with different tourism information presented by haptic display, audio display and both, with 3 different rhythms and 3 levels of amplitude. The results show a main effect of interaction modality, with identification rate highest for information represented in the combined Haptic-Audio display at 86.7%, while no significant effect was found for rhythm or amplitude alone. Qualitative data from the participants indicated that, across all interaction modalities, different levels of amplitude were more difficult to distinguish than different rhythms or different combinations of rhythm and amplitude.



**Keywords**: Haptic, audio, augmented reality.

**Index Terms**: H.5.2 [Information interfaces and presentation]: User Interfaces – Input devices and strategies, Interaction styles.


## 1 Introduction

Even though Augmented Reality (AR) as a concept has existed since the 1960s, it is only over the last two decades that technological advances have established AR as a distinct research field [7]. AR can augment one's view and transform it with the help of a computer or a mobile device with information delivered via modalities such as graphics, audio and even senses such as touch, smell and taste, and thus enhance the user's experience of reality and of the surrounding environment.

AR technology has been widely used in a variety of fields including education, engineering, entertainment, advertisement and TV broadcasting. Tourism, as one of the most productive economic activities in the world, has the potential to obtain great benefit from AR technology. From navigating around unfamiliar environments, to highlighting points of interests to reconstructing historical buildings and experiences with three dimensional (3D) models, AR tourism applications offer multiple ways for the tourist to explore and experience the world while traveling.

In most of the AR tourism applications on the market, the visual display still dominates the interaction between users and mobile devices. But there are well established challenges with the usability of mobile visual displays in general. With often very limited screen space, visual displays can easily become cluttered with information and widgets. Moreover, in mobile situations, looking at the screen is not always feasible for users. For instance, while walking and cycling, it could be inconvenient or dangerous if the user is forced to stop to read the information on screen. It can also be difficult to access visual information when one or both hands are occupied. Furthermore, the visibility of a mobile screen can be compromised through sunlight, movement or illegible text.

Despite these limitations, mobile AR tourism applications today are highly dependent on visual displays, and the non-visual interaction channels are as yet undervalued and underused. The dependence on visual display for mobile AR tourism applications can create problems for users since AR tourism services are typically used in a wide range of contexts. In mobile use situations, looking at the screen is not always feasible. As tourists cannot devote all their visual attention to the mobile application interface while travelling, exploiting multiple interaction modalities such as audio and haptic displays in AR tourism applications becomes more important.

A haptic display can become an important alternative interaction modality when a traditional visual display is not the best option in a mobile computing setting. In addition, the natural role of sound in actions involving mechanical impact and vibration suggests the use of auditory display as an augmentation to haptic interfaces. However, very little published research and evaluation work is available about non-visual interaction channels in AR tourism applications.

Therefore, we are motivated to evaluate the effectiveness of using haptic and auditory displays as outputs to enhance tourist user experiences with mobile AR. In this paper we report the design of a non-visual display with haptic and audio modalities. We conducted an experimental evaluation of the effectiveness of three types of interaction modalities: haptic display only, audio display only and haptic-audio display, with two parameters of the haptic and audio displays: rhythm and amplitude.

## 2 Related Work

Leisure travellers are seeking new tourist experiences that are different and authentic [12], and the motivation to travel has been changing from necessity, to just having fun, to the desire for deep exploration of sites and attractions and more knowledge and learning [8]. Alongside changes in the tourism paradigm, tourists are also increasingly seeking applications and tools to enable and improve such new and meaningful experiences [10].

Kansa and Wilde described characteristics of information and service design by exploring the needs and motivations of tourists [6]. They suggested approaches to delivering tourist location-based services based on 'low barrier of entry' principles of web architecture. They also pointed out that users sometimes have the


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motivation and inclination to perceive what is happening behind the scenes, and increasing the degree of transparency can enhance the service innovation.

AR's attributes render it uniquely suitable for the visualization of spatial environments, underpinning why AR is commonly exploited for purposes of urban exploration and heritage reconstruction in the tourism industry [4]. One of the first cultural heritage sites that benefited from an augmented virtual reconstruction of an ancient temple was Olympia in Greece, where researchers developed the ArcheoGuide AR system [4]. Instead of physically rebuilding historical remains and thus interfering with archaeological research, AR techniques are used in this project to present virtual reconstructions of the artifacts in the real environment. Visitors equipped with a mobile computer are able to appreciate the real site while experiencing visualizations of the virtual reconstructions.

Currently, smartphones combine necessary technologies for AR such as a powerful processor, rear facing camera, GPS, compass and many other sensors in one small, mobile device. Smartphones have introduced AR to the mass market, which has enormous potential for tourism [16]. Most AR tourism applications on mobile devices focus on mixing reality with virtual contents on the screen, which relies heavily on the visual display. However, given that the visual display may not be suitable in some scenarios, alternative modalities become potentially important in situations where interaction through a visual display is not feasible or effective. Haptic and audio displays are potential non-visual alternatives for AR tourism applications.

Many tour guide projects and applications have recently started employing the combination of audio and tactile feedback. For example, PocketNavigator [11] is a pedestrian navigation application with a Tactile Compass, which uses vibration patterns to guide a user along a route or to a certain destination. Giachritsis et al. described a method for developing intuitive navigation patterns representing basic directions, landmarks and actions [3], and they found that simple directions were easier to identify than landmarks or actions. Srikulwong and O'Neill [14] investigated wearable tactile displays for pedestrian navigation, and in a field evaluation they found users' navigation accuracy with a tactile-based system was equivalent to that with a visual-based system, while users' route completion time was significantly faster with a tactile-based directional display.

Haptic and audio feedback have also been used and tested in other applications. McGookin and Brewster [9] investigated people's perception of auditory displays by encoding different information into 'earcons'. Different earcons represented rides that may appear in an amusement/theme park. Three parameters of earcons were used to encode information about the ride: timbre, intensity and register. Each earcon encoded the type of ride, the intensity of the ride, and the cost of the ride.

There are many different attributes that can be used in haptic and audio displays. For example, Brown et al. investigated people's learning of tactile messages [1] that represented alerts in an electronic diary to remind the user of an upcoming appointment. They explored three different parameters for vibration feedback and selected three parameters: rhythm, roughness and spatial location. Each of the 3 parameters represented a particular meaning: type, importance and time remaining before the appointment. They found identification rates for three-parameter tactile feedback were not satisfactory, and reducing the number of levels of each parameter could be a possible solution. Ternes and MacLean [15] investigated rhythm in combination with frequency and amplitude for haptic icons, and found that note length and unevenness are two primary characteristics in enabling the user to distinguish tactile rhythms. Ryu et al. [13] reported investigations identifying the detection thresholds of frequency and amplitude range using mobile devices, as well as the perceived intensity. Chen et al. [2] also investigated information transfer associated with tactile-audio signal sets and their results suggest that supplemental audio signals can be useful for disambiguating tactile signals. However, although there has been a lot of work on haptic and audio feedback and, independently, on mobile AR tourism applications, very little previous research investigates the use of non-visual displays for mobile tourism applications.

## 3 Non-visual Display Design for Tourism Information

Normally the most common device available for a tourist is a mobile device, typically a smartphone. Thus in this research, rather than using a specially developed tactile device, we deliberately used only mobile devices commonly available in the consumer market.

Rhythm is considered to be a very effective cue in both touch and sound [5]. Amplitude (i.e. intensity of touch and volume of sound) has also been used to present information with haptic and audio displays [1]. Given that current mass market consumer mobile devices can support both rhythm and amplitude for haptic and audio feedback very well, we used rhythm and amplitude in our non-visual feedback design for presenting tourism information on mobile devices. We investigated the effects of rhythm and amplitude in an audio display, a haptic display and a combined audio-haptic display.

We ran the study in the city of Bath, UK, which is a World Heritage Site and major tourist centre. Three distinct rhythms were used to represent three different historical themes of particular interest in the context of Bath as a tourist venue: water (Figure 1a), architecture (Figure 1b) and people (Figure 1c). The combination of different intervals and numbers of pulses made the rhythms distinct from each other. In figure 1, these rhythms are presented in the standard musical notation on a single line since no pitch information is required.

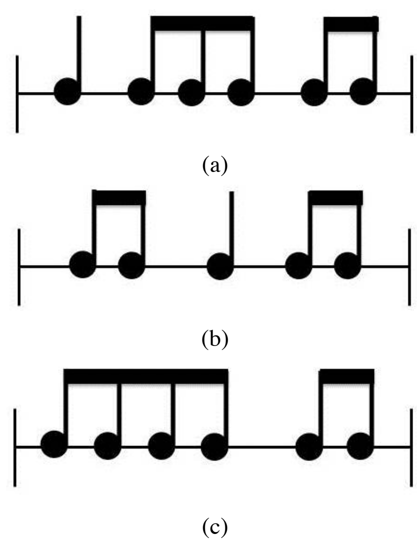


Figure 1: Different rhythms to represent three historical themes.

In addition to the three historical themes, we represented three historical periods of particular interest to tourists in the city of Bath. Three distinct amplitudes were used to represent the Ancient (Low amplitude), Medieval (Mid) and Georgian (High) historical periods. The haptic effects of different amplitude were generated using the Immersion Haptic SDK[1] on an LG Optimus

[1] http://www.immersion.com/products/haptic-sdk/

P970 smartphone, vibrating at 33% intensity (Low), 66% intensity (Mid) and 100% intensity (High). The corresponding three amplitude conditions – 0.3 (Low), 0.6 (Mid) and 1.0 (High) – for the audio display were based on the volume settings from 0.0 to 1.0 in the experimental mobile application that we developed running on the Android platform on the smartphone (Figure 2).

## 4 Experimental Evaluation

Based on the haptic and audio display design outlined in the previous section, we designed and conducted an experiment to evaluate the effectiveness of such a non-visual display in the context of a mobile tourism application.

### 4.1 Equipment and Setting

We used an LG Optimus P970 to provide the haptic and audio displays through its vibration actuator and speaker respectively. This Android smartphone supports control of vibration amplitude using Immersion TouchSense® Haptic Feedback Technology [2]. It has a 4-inch visual display and weighs 109g.

### 4.2 Independent Variables

The independent variables were Interaction Modality (Haptic, Audio, Haptic-Audio), Rhythm (3 rhythms as shown in Figure 1) and Amplitude (Low, Mid, High).

### 4.3 Participants

Thirty participants volunteered to take part in this study. The participants were all postgraduate students, aged from 21 to 29. There were 19 males and 11 females. All participants had experience in using touch screen smartphones and were familiar with sound and vibration generated by smartphones.

### 4.4 Experimental Design

A repeated measures mixed design was used. The 30 participants were separated into 3 groups, one for each Interaction Modality, giving 10 participants in each group. Within each group, every participant was asked to identify the 9 combinations of 3 different Rhythm types and 3 Amplitude levels for that interaction modality.

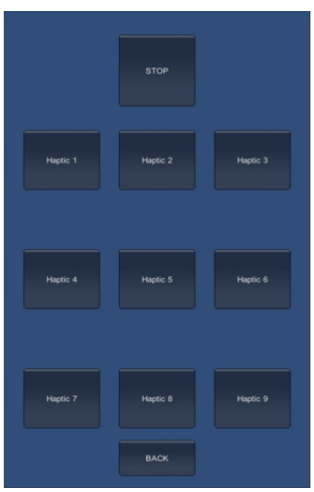


Figure 2: User interface of the experimental mobile application.

Each participant was given a brief introduction followed by a 10 minute self-guided exploration, trying all possible combinations of the different Rhythm types and Amplitudes with the 3 different Interaction Modalities. In the subsequent testing phase, the participant held the smartphone in her hands and was asked to identify all 9 combinations of 3 Rhythm types and 3 Amplitude levels (Figure 3). For each representation, the participant was required to write on an answer sheet the historical theme and period represented by the display. The presentation order was randomized, and each combination was presented for 5 seconds. At the end, qualitative data was collected from the participant by questionnaire on all three types of interaction modalities.

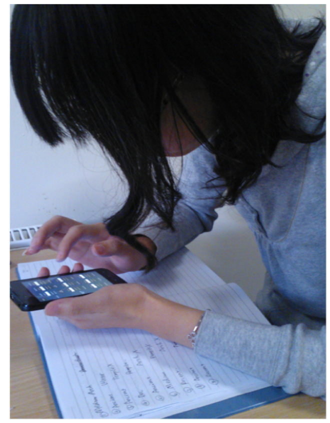

Figure 3: Experimental setting.

## 5 Results

An identification was considered to be correct only when both rhythm and amplitude were correctly identified. Correct responses were logged and the percentages of correct identifications were calculated. Participant feedback was also collected after the tests.

### 5.1 Identification Rate

The results for overall correct responses to all three types of display showed an overall average identification rate of 76.6%. The identification rate with Haptic-Audio was the highest at 86.7%. The identification rate with Haptic was 70%, and with Audio was 73.3% (Figure 4).

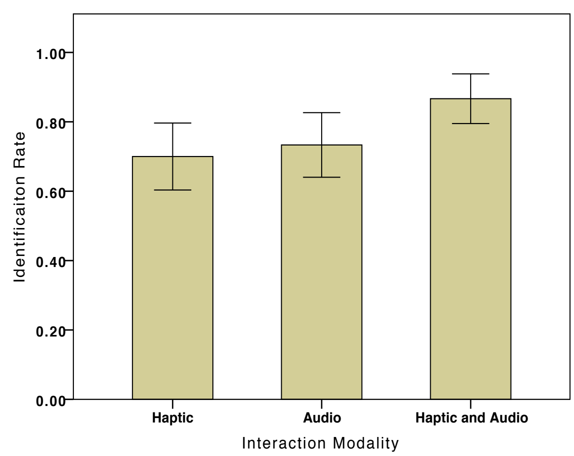


Figure 4: Mean identification rate of different Interaction Modality (error bars represent 95% confidence intervals).

A repeated measures ANOVA for Interaction Modality x Amplitude x Rhythm was performed. A main effect was found for Interaction Modality ($F_{1, 27}=3.40$, $p<0.05$) but no significant difference was found in post hoc Bonferroni pairwise comparisons

[2] http://www.immersion.com/products/touchsense-tactile-feedback/

amongst the different modalities ($p > 0.05$). No significant effect was found for either Amplitude ($F_{2,54}$=0.07, p=0.94) or Rhythm ($F_{2,54}$=1.21, p=0.31). No significant interaction effect was found for Amplitude x Rhythm ($F_{4,108}$=0.12, p=0.98), Amplitude x Modality ($F_{4,54}$=1.04, p=0.40), or Rhythm x Modality ($F_{4,54}$=0.26, p=0.91). The overall identification rates of amplitude and rhythm were 76.7% and 76.6% respectively.

### 5.2 Participant Feedback

Participants were asked if they found it hard to distinguish between the different rhythms and between the different amplitudes. Across all interaction modalities, more than half of the participants felt that different amplitude levels were difficult to distinguish (Figure 4). On the other hand, across all interaction modalities, fewer people felt that rhythm, or rhythm and amplitude together, were difficult to distinguish (Figure 5).

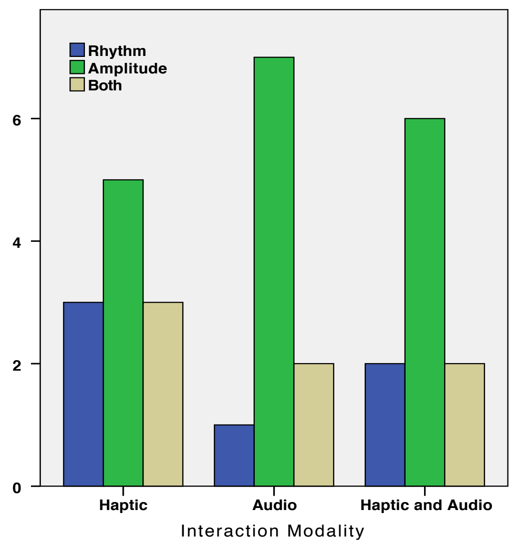


Figure 5: Participants' reported difficulty distinguishing the different levels of Rhythm and Amplitude for each interaction modality.

## 6 Discussion and Conclusion

We evaluated the effectiveness of haptic and audio displays with two parameters of rhythm and amplitude to represent tourist information. Experimental results showed a main effect of interaction modality. The overall identification rate was more than 75%, with Haptic-Audio displays the highest performing at 86.7%. Tourist information (e.g. historical periods or themes) could be presented and recognized effectively with combinations of different attributes (e.g. amplitude and rhythms) on mobile devices with haptic and audio outputs.

Providing haptic and audio displays together achieved the best performance, however, haptic or audio display alone could also be effective. The identification rates with Haptic display alone and Audio display alone were very similar (Figure 3). Given tourism and leisure contexts in which audio feedback cannot effectively be used, such as quiet places (e.g. museums or classical concerts) and noisy places (e.g. busy streets or rock concerts), haptic displays could be considered more by application designers.

Furthermore, subjective feedback from participants showed different amplitude levels were more difficult to distinguish than different rhythms, which is similar to the results in [1]. This suggests that designers should leverage rhythm more for haptic and audio displays, and should consider reducing the number of amplitude levels if possible as suggested in [1], perhaps using no more than three levels of amplitude for audio displays.

Future work could include the design and development of different types of haptic and audio devices for different scenarios, for example different sizes and form factors to support various wearing and holding styles, as well as different use environments and more potential rhythm and amplitude variations and combinations. Further studies in real tourism settings could also be conducted to develop a deeper understanding of practical uses.

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